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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : C08G 69/48, 69/08, 69/16

A1

(11) International Publication Number: WO 00/35992

(43) International Publication Date: 22 June 2000 (22.06.00)

(21) International Application Number: PCT/NL99/00764

(22) International Filing Date: 13 December 1999 (13.12.99)

(30) Priority Data:
1010819 16 December 1998 (16.12.98) NL

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(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: INTRINSICALLY GEL–FREE, RANDOMLY BRANCHED POLYAMIDE

(57) Abstract

The invention relates to a randomly branched polyamide comprising at least units derived from: 1. AB mononers; 2. at least one compound I, being a carboxylic acid (A_v) having a functionality $v \geq 2$ or an amine (B_w) having a functionality $w \geq 2$; 3. at least one compound II, being a carboxylic acid (A_v) having a functionality $v \geq 3$ or an amine (B_w) having a functionality $w \geq 3$, compound II being a carboxylic acid if compound I is an amine or compound II being an amine if compound I is a carboxylic acid and the amounts of all units derived from carboxylic acids and amines in the polyamide satisfying conditions as mentioned in claim 1. The composition of the randomly branched polyamide is such that it cannot form a crosslinked polyamide (and thus no gels, either), in particular during the prepolymerization, the polymerization, the post–condensation, the processing and the storage of the randomly branched polyamide, and this at a variety of ambient factors, for instance at elevated temperature and pressure. The polyamide is eminently suitable for the production of fibre and film, in particular for flat film.

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INTRINSICALLY GEL-FREE, RANDOMLY BRANCHED POLYAMIDE

The invention relates to a randomly branched polyamide comprising at least units derived from:

1. AB monomers,
2. at least one compound I, being a carboxylic acid (A_v) having a functionality $v \geq 2$ or an amine (B_w) having a functionality $w \geq 2$,
3. at least one compound II, being a carboxylic acid (A_v) having a functionality $v \geq 3$ or an amine (B_w) having a functionality $w \geq 3$, compound II being a carboxylic acid if compound I is an amine or compound II being an amine if compound I is a carboxylic acid.

In the context of this application, with the term "randomly branched" is meant that the branching points are randomly distributed in the polyamide chain.

Such a randomly branched polyamide is known from EP-345.648-B1. However, a problem encountered with the randomly branched polyamide according to EP-345.648-B1 is that the randomly branched polyamide is not intrinsically gel-free so that, while the randomly branched polyamide can for instance be obtained as a gel-free melt, during further processing of the randomly branched polyamide, gel formation may as yet occur. In the context of this application gel formation is understood to be a process involving the formation of a network in a polymer material. Gel formation gives rise to, among other things, the formation of visible inhomogeneities ("gels") during processing of the

randomly branched polyamide into, for instance, films or fibres and to deterioration of the mechanical properties of polyamide objects obtained from the randomly branched polyamide. It is also known that when randomly branched polyamide is processed in equipment where local overheating may take place or where polyamide material may accumulate, for instance in extruders and mixers, it may contain strongly crosslinked polyamide.

It is desirable to have intrinsically gel-free randomly branched polyamide available. In the context of this application "intrinsically gel-free" is understood to mean that the composition of the randomly branched polyamide is such that it cannot form crosslinked polyamide (and therefore no gels), in particular during the prepolymerization, the polymerization, the post-condensation, the processing, for instance into films or fibres, and the storage of the randomly branched polyamide, and this at a variety of ambient factors, for instance at elevated temperature and pressure.

Although the prevention of gel formation in polymeric materials has been receiving a great deal of attention in practice, at this point of time neither a structural nor a systematic approach is known to provide an adequate solution to the problem of obtaining intrinsically gel-free, randomly branched polyamide from AB monomers.

It is the aim of the inventors to provide such an intrinsically gel-free, randomly branched polyamide comprising at least units derived from:

1. AB monomers,
2. at least one compound I, being a carboxylic acid (A_v)

having a functionality $v \geq 2$ or an amine (B_w) having a functionality $w \geq 2$,

3. at least one compound II, being a carboxylic acid (A_v) having a functionality $v \geq 3$ or an amine (B_w) having a functionality $w \geq 3$, compound II being a carboxylic acid if compound I is an amine or compound II being an amine if compound I is a carboxylic acid.

This aim is achieved when the amounts of all units derived from carboxylic acids and amines in the polyamide satisfy formula 1

$$P < 1 / [(F_A - 1).(F_B - 1)] \qquad (1)$$

where:

$$P = [\Sigma (n_i.f_i)]_X / [\Sigma (n_i.f_i)]_Y \qquad (2)$$

where $P \leq 1$ and either X = A and Y = B, or X = B and Y = A, and

$$F_x = \Sigma (n_i.f_i^2) / \Sigma(n_i.f_i) \qquad (3)$$

for, respectively, all carboxylic acids (X = A) and all amines (X = B), where f_i is the functionality of either the carboxylic acid ($f_i = v_i$) or amine ($f_i = w_i$), n_i being the number of moles of the carboxylic acid or amine and the summation involving all units derived from carboxylic acids and amines in the polyamide.

In the context of the present invention AB monomer is understood to be a monomer that has both a carboxylic acid group (A) and an amine group (B).

In the context of the present application

compound I and compound II are also understood to be mixtures of several carboxylic acids having the same functionality or mixtures of several amines having the same functionality.

In the context of the present application carboxylic acid and amine are understood to be, respectively, a compound which, besides one or more carboxylic acid groups, does not carry any amine groups and the other way round. It therefore follows that units derived from carboxylic acids or amines in the polymer have a chemical composition that differs from that of the units derived from the AB monomers. Carboxylic acid group is in the context of the present application understood to be a group that can form a covalent bond with an amine group, for instance -COOH, -COHal (Hal = halogen), $-CO_2R$ in which R is an alkyl residue with 1 to 20 carbon atoms and $-SO_2Hal$ (Hal = halogen).

In the context of the present application functionality is understood to be the number of functional groups in the carboxylic acid or the amine that can form a bond with other carboxylic acids, amines or AB monomers to form the randomly branched polyamide according to the invention. A functional group that cannot form this bond, for instance a sterically hindered amine group or an aromatic amine group, is not considered as a functional group in determining the functionality. Likewise, the functionality is equated to 1 if two functional groups at a compound are both involved in a single bond with a third functional group, for instance two COOH groups that are close together which form an imide bond with an amine, for instance in the compound orthodicarboxy-benzene.

Preferably, the functionality v or w of compound I can be chosen from 2, 3, 4, 5 and 6. More preferably, the functionality of compound I is 2. Preferably, the functionality v or w of compound II can be chosen from 3, 4, 5 and 6. More preferably, the functionality of compound II is 3.

Eligible AB monomers are all AB monomers that can be used for the production of polyamides, in particular α,ω-amino acids and/or lactams, for instance caprolactam, laurine lactam and dodecalactam, as well as the corresponding amino acids and aromatic amino acids, for instance p-(aminomethyl)-benzoic acid. Preferably, the lactam is ε-caprolactam.

Eligible carboxylic acids (A_v) are preferably difunctional carboxylic acids, for instance adipic acid, dodecane dicarboxylic acid, isophthalic acid and terephthalic acid and trifunctional carboxylic acids, for instance 1,3,5-tris(caproic acid)melamine, trimesic acid and trimeric fatty acids with 50-60 carbon atoms as well as esters and anhydrides of said carboxylic acids. Preferably, the difunctional carboxylic acid is terephthalic acid. Preferably, the trifunctional carboxylic acid is 1,3,5-tris(caproic acid)melamine (TCAM) or trimesic acid.

Eligible amines (B_w) are preferably difunctional amines, for instance diaminobutane, diaminohexane, diaminododecane, cyclic amines, for instance 1,4-diaminocyclohexane, 4,4'-diaminobicyclohexylamine, 1,3- and 1,4-xylylene diamine and trifunctional amines, for instance trisaminononane and bis(hexamethylene triamine). Preferably, the difunctional amine is 1,6-hexamethylene diamine. Preferably, the trifunctional amine is

bis(hexamethylene triamine).

Besides the units derived from compounds I and II according to the invention also other units derived from carboxylic acids and amines may be present, for instance monofunctional carboxylic acids and amines (chain terminators).

Although the aim of the invention according to EP-345.648-B1 is not the aim of the present invention, while said publication does not mention the measures according to the present invention, either, it does mention, besides a number of randomly branched polyamides that do not satisfy the measures according to the present invention, also a number of randomly branched polyamides which coincidentally satisfy the measures according to the invention. These randomly branched polyamides are excluded from the application, more specifically the randomly branched polyamides that are built up of units derived from carboxylic acids (A_v) having a functionality v and amines (B_w) having a functionality w, in the following amounts (in μmol/g of polyamide):

- B_1 (20), B_3 (60) and A_2 (20)
- B_1 (10), B_3 (60) and A_2 (30)
- B_1 (120), B_2 (30) and A_3 (60)
- B_1 (150), B_2 (30) and A_3 (70)
- B_1 (170), B_3 (30), A_2 (60) and A_3 (60)

The intrinsically gel-free, randomly branched polyamide according to the invention can be produced using methods known to one skilled in the art, both via a batch process and via a continuous process. According to a first embodiment all AB monomers,

carboxylic acids and amines are polymerized in amounts according to the invention in a reactor at a suitable temperature and pressure. According to a second embodiment the carboxylic acids and amines are added to a melt of a polyamide comprising units derived from AB monomers.

The gel-free, randomly branched polyamide according to the invention can also contain the customary additives, for instance flame retardants, fillers, release agents, lubricants and colourants.

The intrinsically gel-free, randomly branched polyamide according to the invention is eminently suitable for the production of fibre, film, foams and moulded articles. In particular, the intrinsically gel-free, randomly branched polyamide according to the invention is eminently suitable for the production of thin film, in particular flat film. The inventors have established that no gels could be observed in said thin film obtained with the polyamide according to the invention. Another surprising advantage of the polyamide according to the invention is that no or hardly any neck-in occurs in the production of flat film. Neck-in is the decrease in the ratio of film width to die width during the film forming process. This surprising advantage allows films to be formed in a simple manner without the known attendant measures to prevent neck-in, for instance cooling of the film edges during the film forming process.

The invention therefore also relates to a process for the production of film obtained from the polyamide according to the invention, as well as to the film obtained with the polyamide according to the invention.

The invention will now be elucidated on the basis of examples, without however being limited thereto.

Examples

Examples I-VIII : Graphical development of the gel-free concentration range

For a number of combinations of carboxylic acids and amines (Table 1), formulas (1)-(3) were developed into a graphical representation for a combination of three carboxylic acids or amines (Figures 1-8), without however limiting the invention to the examples given. In the figures it was shown what amounts (expressed as mole fractions) of units derived from carboxylic acids and amines an intrinsically gel-free, randomly branched polyamide can contain. In the concentration range indicated by small circles the randomly branched polyamide is non-intrinsically gel-free. It is remarkable to note that the intrinsically gel-free nature of a randomly branched polyamide does not depend on the absolute amount of units derived from a carboxylic acid or amine, but only on the relative ratio of the units derived from the carboxylic acids and amines. This also means that the intrinsically gel-free nature of a randomly branched polyamide according to the invention does not depend on the amount of units derived from AB monomers. A third remarkable fact is that in the polyamide according to the invention all units derived from carboxylic acids can be replaced by amines, and the other way round, without this changing the gel-free nature of a polyamide. For instance, the concentration range for the units derived from carboxylic acids A_1 and A_3 and the amine B_2 is the same

as that for units derived from amines B_1 and B_3 and the carboxylic acid A_2 (Figure 1).

Table 1: Combinations of carboxylic acids and amines

Example	Carboxylic acids	Amines	Figure
I	A_1, A_3	B_2	1
II	A_1, A_3	B_3	2
III	A_1, A_4	B_2	3
IV	A_1, A_4	B_3	4
V	A_1, A_5	B_2	5
VI	A_1, A_5	B_3	6
VII	A_1, A_6	B_2	7
VIII	A_1, A_6	B_3	8

Preparation of gel-free, randomly branched polyamides

Process 1

100 g of ε-caprolactam, 1 g of ε-aminocaproic acid, 2 g of water and varying amounts of carboxylic acids and amines (see Table 2 for the molar ratios) were mixed in a glass tube at 90°C. The tube was equipped with a reflux cooler and was purged three times with vacuum/nitrogen before use, following which the reaction mixture was heated to 260-270°C in a nitrogen atmosphere and was subsequently kept at this temperature for 11 hours. After cooling, the tube was broken and its contents ground and washed three times in boiling water so as to remove any unreacted caprolactam and low-molecular oligomers and subsequently dried for 24 hours in a vacuum at 80°C. The polymer obtained was white. The washed and dried

polymers were subjected to a number of analyses such as melt viscosity and intrinsic viscosity. The melt viscosity was determined using a Rheometrix 800 plate/plate apparatus as so-called zero viscosity at 230°C, in other words the dynamic melt viscosity at zero shear force. The intrinsic viscosity was determined by means of a three-point measurement (3, 4 and 5 g/l) in 85% formic acid at 25°C. All polymers in Table 1 were prepared in this way.

Process 2

In a 5-litre reactor 3.5 kg of ε-caprolactam, 35 g of ε-aminocaproic acid, 70 g of water and the varying amounts of additives were combined. The temperature of the reaction mixture was kept at 90°C for 5 hours, after which the mixture was heated to 275°C in about 2 hours and was kept at that temperature for 5 hours. Subsequently, the temperature was lowered to 240°C in 60 minutes and kept at that value for 3.5 hours. Next, the reactor contents were drained in a nitrogen atmosphere at 1 bar overpressure. The polymer thread flowing out the reactor was cooled in ice water and chopped into granules, which were washed with water at 100°C and subsequently dried.

Post-condensation:

The polymer obtained by means of processes 1 and 2 was post-condensed for 10 hours at 190°C in a vacuum and with a nitrogen leak.

Examples IX-XXXII

Process 1 was used to prepare a number of polyamides, the compositions being given in Table 2. In

none of the polyamides was crosslinking observed during or after the polymerization.

Table 2: Intrinsically gel-free polyamide compositions (amounts in moles).

Ex.	A_1	B_1	A_2	B_2	A_3	B_3	AB monomer
IX	1	-	-	0.25	0.25	-	300
X	1	-	-	0.5	0.5	-	300
XI	1	-	-	0.75	0.75	-	300
XII	1	-	-	1	1	-	300
XIII	1	-	-	2	2	-	300
XIV	-	1	0.25	-	-	0.25	300
XV	-	1	0.5	-	-	0.5	300
XVI	-	1	1	-	-	1	300
XVII	-	1	2	-	-	2	300
XVIII	1	1.25	-	0.25	0.25	-	300
XIX	1	1.5	-	0.5	0.5	-	300
XX	1	2	-	1	1	-	300
XXI	1	3	-	2	2	-	300
XXII	1	1.5	-	0.5	0.5	-	300
XXIII	0.5	-	-	-	0.5	-	300
XXIV	0.33	-	-	0.67	1.33	-	300
XXV	0.5	-	-	0.5	1	-	300
XXVI	0.6	-	-	0.4	0.8	-	300
XXVII	0.67	-	-	0.33	0.67	-	300
XXVII I	2	-	-	2	1	-	300
XXIX	0.67	-	-	0.67	1	-	300
XXX	0.5	-	-	0.5	1	-	300
XXXI	0.57	-	-	0.29	0.57	-	300
XXXII	1.33	-	-	1.67	1.33	-	300

Explanation of the abbreviations :

A_1 : benzoic acid

B_1 : hexylamine

A_2 : adipic acid

B_2 : hexamethylene diamine

A_3 : 1,3,5-tris(caproic acid)melamine

B_3 : bis(hexamethylene)triamine

AB monomer : ε-caprolactam

Comparative examples A-G according to EP-B1-345.638

Process 1 was used to prepare a number of polyamides, their compositions being given in Table 3. In all polyamides crosslinking was observed during or after the polymerization.

Table 3 : Comparative examples according to EP-B1-345.638.

Comparative example	Example acc. to EP-B1-345.638 (Table 2)	AB monomer	B_1 (L-252)	B_3 (N-TEA)	A_2 (ADS)	A_3 (TMS)	gel formation
A	10	aminolaurine acid	180	30	-	90	yes
B	11	aminolaurine acid	190	30	-	92	yes
C	13	aminolaurine acid	176	28	46	56	yes
D	15	caprolactam	210	30	-	100	yes
E	16	caprolactam	210	30	-	100	yes
F	17	caprolactam	176	28	46	56	yes
G	18	caprolactam	124	20	32	40	yes

Explanation of the abbreviations:

L-252 : 3-amino-1-cyclohexyl-aminopropane
N-TEA : nitrilotriethane amine
ADS : adipic acid
TMS : trimesic acid

Mechanical properties of the polyamide according to the invention

Surprisingly, it was also found that the polyamide according to the invention combines a high melt strength with a high melt drawing degree compared to non-branched polyamide. This is shown in Figure 9.

CLAIMS

1. Intrinsically gel-free, randomly branched polyamide comprising at least units derived from:
   1. AB monomers,
   2. at least one compound I, being a carboxylic acid (A_v) having a functionality $v \geq 2$ or an amine (B_w) having a functionality $w \geq 2$,
   3. at least one compound II, being a carboxylic acid (A_v) having a functionality $v \geq 3$ or an amine (B_w) having a functionality $w \geq 3$,

   compound II being a carboxylic acid if compound I is an amine or compound II being an amine if compound I is a carboxylic acid, characterized in that the amounts of units derived from all carboxylic acids and amines in the polyamide satisfy formula 1

$$P < 1 / [(F_A - 1).(F_B - 1)] \qquad (1)$$

where:

$$P = [\Sigma (n_i.f_i)]_X / [\Sigma (n_i.f_i)]_Y \qquad (2)$$

where $P \leq 1$ and either $X = A$ and $Y = B$, or $X = B$ and $Y = A$, and

$$F_x = \Sigma (n_i.f_i^2) / \Sigma(n_i.f_i) \qquad (3)$$

for, respectively, all carboxylic acids ($X = A$) and all amines ($X = B$), where f_i is the functionality of either the carboxylic acid ($f_i = v_i$) or amine ($f_i = w_i$), n_i being the number of

moles of the carboxylic acid or amine and the summation involving all units derived from carboxylic acids and amines in the polyamide except:

randomly branched polyamides comprising units derived from carboxylic acids (A_v) having a functionality v and amines (B_w) having a functionality w, in the following amounts (in μmol/g of polyamide):

- B_1 (20), B_3 (60) and A_2 (20)
- B_1 (10), B_3 (60) and A_2 (30)
- B_1 (120), B_2 (30) and A_3 (60)
- B_1 (150), B_2 (30) and A_3 (70)
- B_1 (170), B_3 (30), A_2 (60) and A_3 (60).

2. Polyamide according to claim 1, characterized in that the functionality of compound I can be chosen from 2, 3, 4, 5 and 6 and the functionality of compound II can be chosen from 3, 4, 5 and 6.

3. Polyamide according to either of claims 1-2, characterized in that the functionality of compound I is 2 and the functionality of compound II is 3.

4. Polyamide according to claim 3, characterized in that also at least a unit derived from monofunctional carboxylic acid or amine is present.

5. Polyamide according to either of claims 3-4, characterized in that compound I is chosen from the group formed by terephthalic acid and 1,6-hexa-methylene diamine.

6. Polyamide according to any one of claims 3-5, characterized in that compound II is chosen from

the group formed by 1,3,5-tris(caproic acid)-melamine, trimesic acid and bis(hexamethylene triamine).

7. Polyamide according to any one of claims 1-6, characterized in that the AB monomer is an α,ω-amino acid and/or a lactam.

8. Polyamide according to claim 7, characterized in that the lactam is ε-caprolactam.

9. Process for the preparation of a polyamide film, characterized in that a polyamide according to any one of claims 1-8 is chosen as polyamide.

10. Fibre, film, foam or moulded article obtained from a polyamide according to any one of claims 1-8.

11. Flat film obtained from a polyamide according to any one of claims 1-8.

12. Polyamide as described and elucidated on the basis of the examples.

WO 00/35992 PCT/NL99/00764

FIG. 1

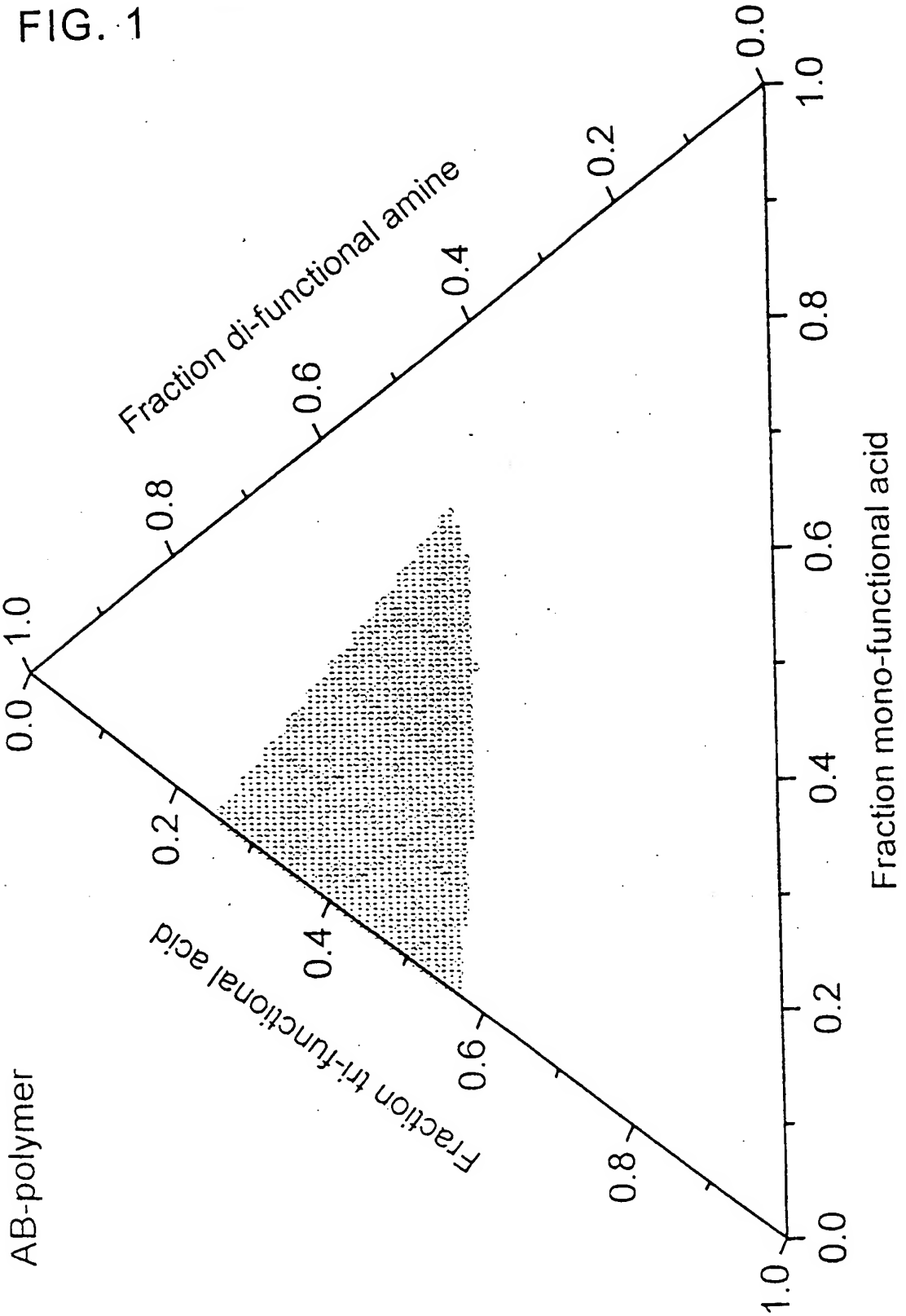


FIG. 2

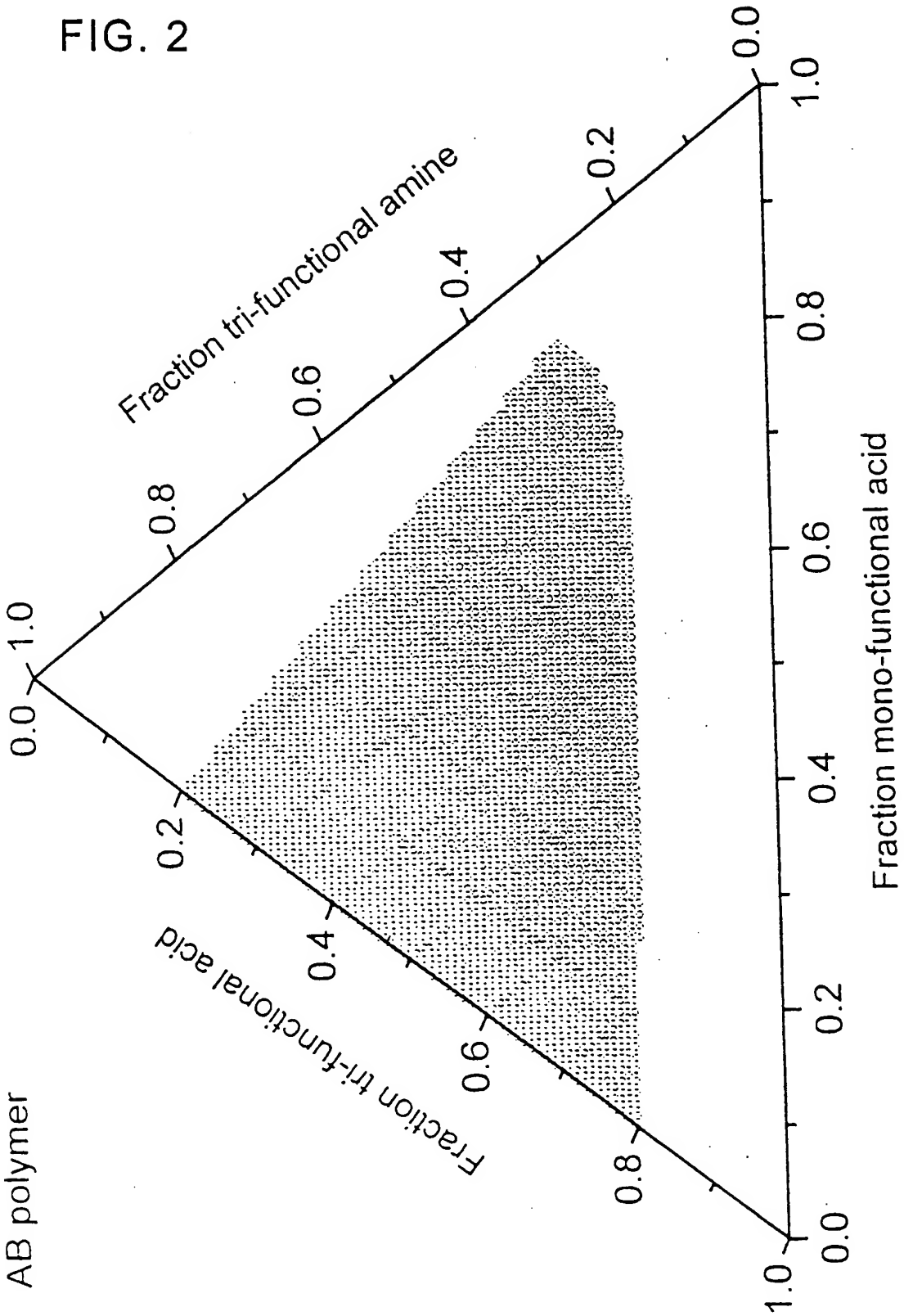

Fraction tri-functional amine
0.0
0.2
0.4
0.6
0.8
1.0
Fraction mono-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
Fraction tri-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
AB polymer

FIG. 3

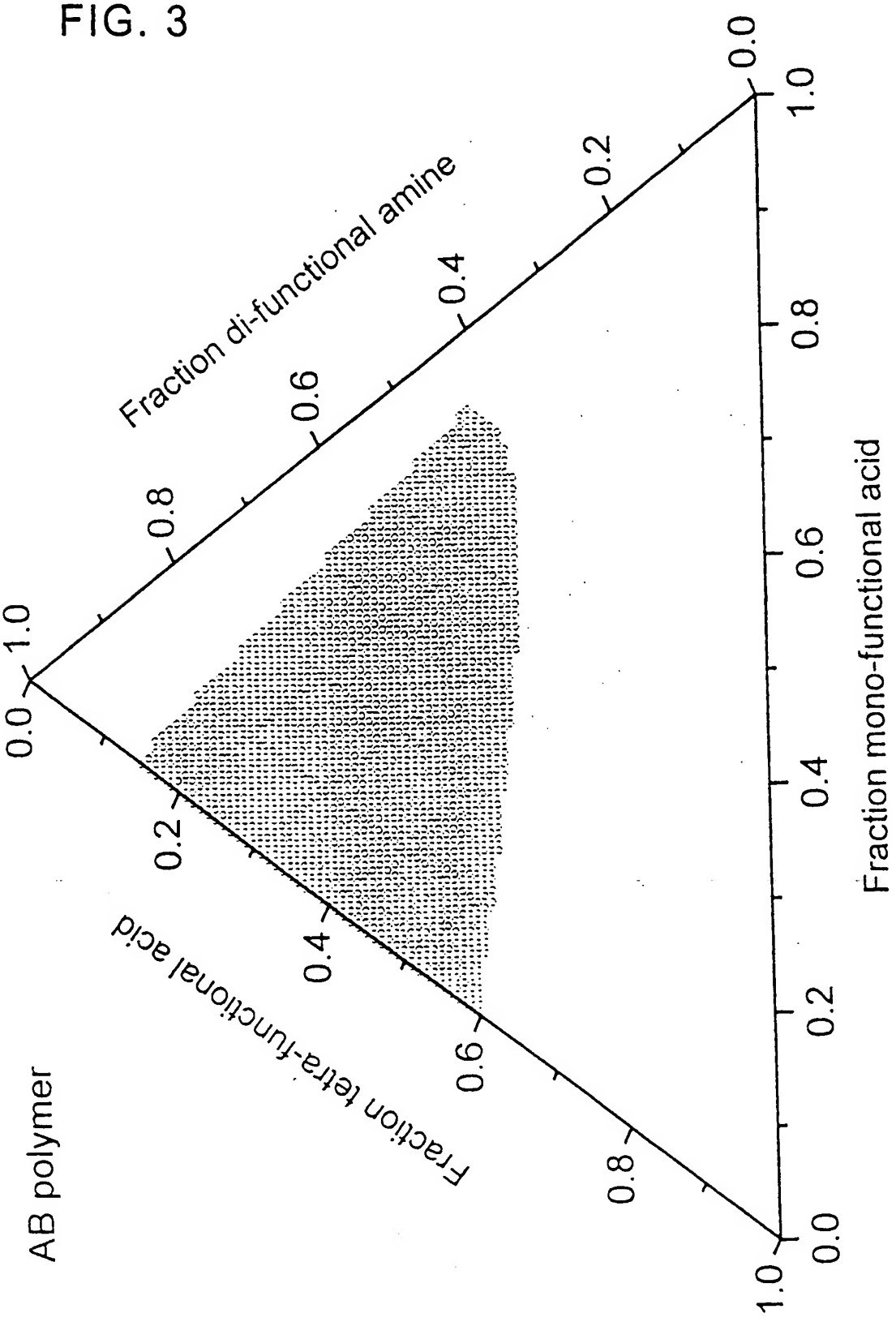

Fraction di-functional amine
0.0
0.2
0.4
0.6
0.8
1.0
Fraction mono-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
Fraction tetra-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
AB polymer

FIG. 4

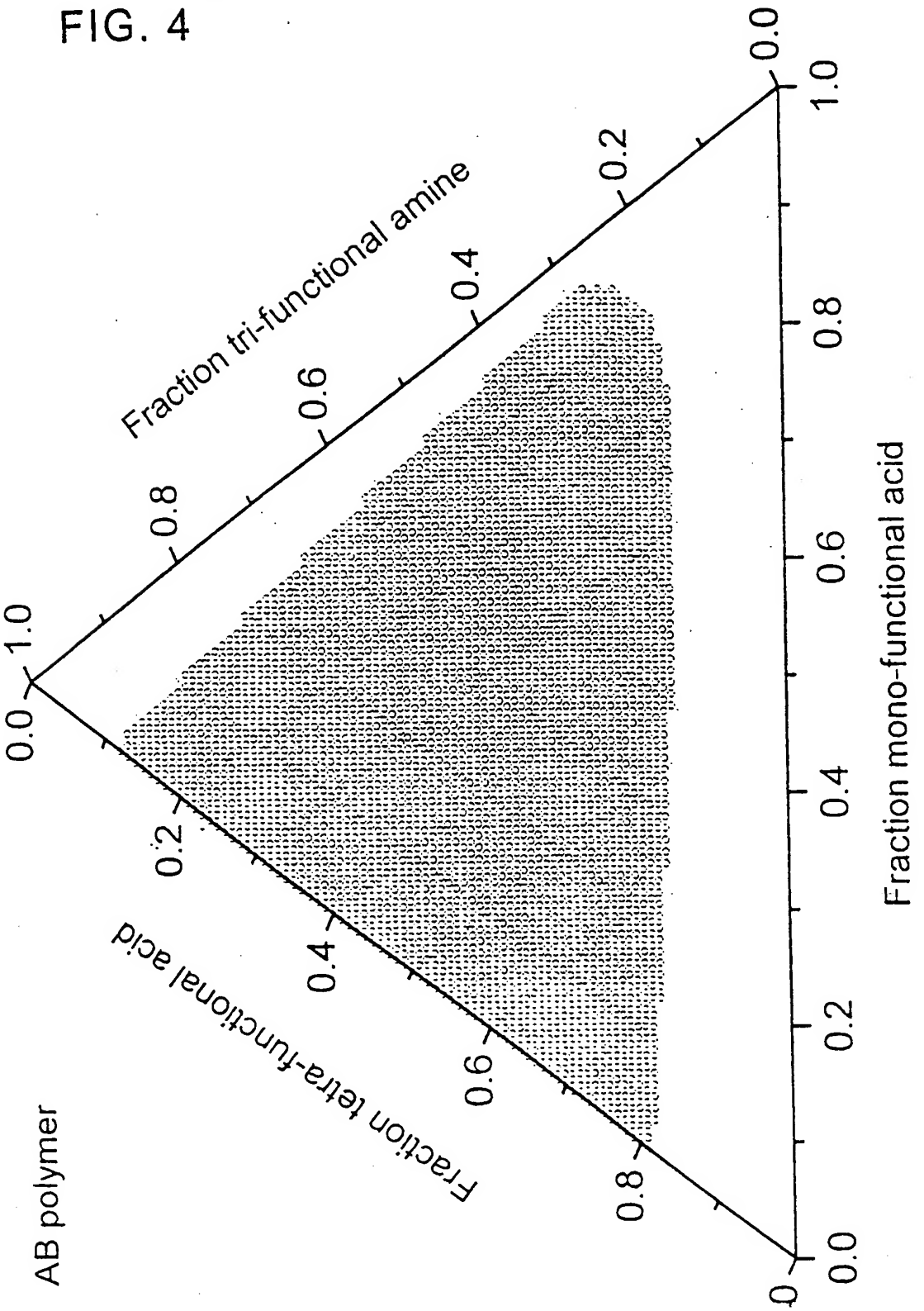

Fraction tri-functional amine
0.0
0.2
0.4
0.6
0.8
1.0
Fraction mono-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
Fraction tetra-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
AB polymer

FIG. 5

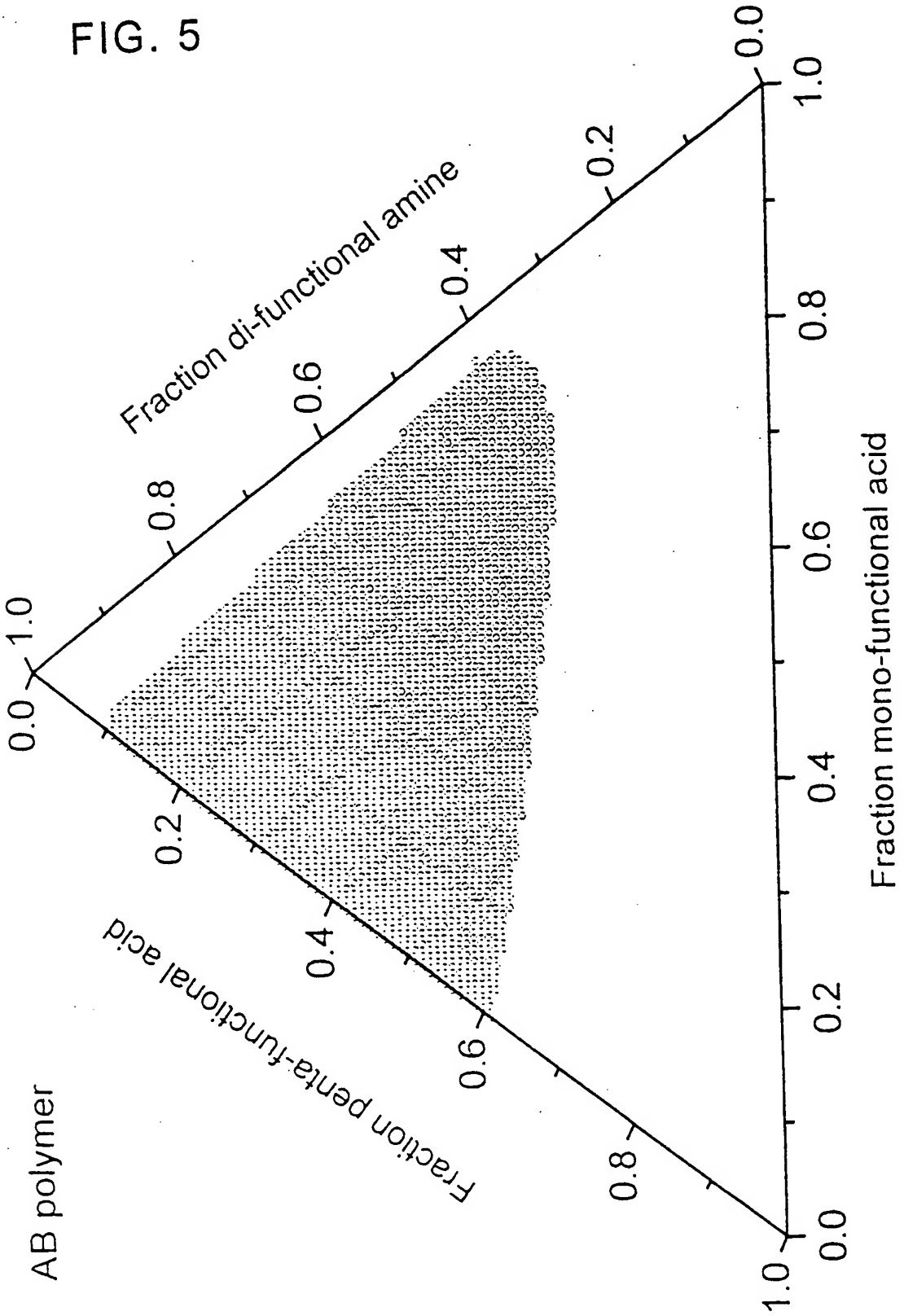

Fraction di-functional amine
0.0
0.2
0.4
0.6
0.8
1.0
Fraction mono-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
Fraction penta-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
AB polymer

FIG. 6

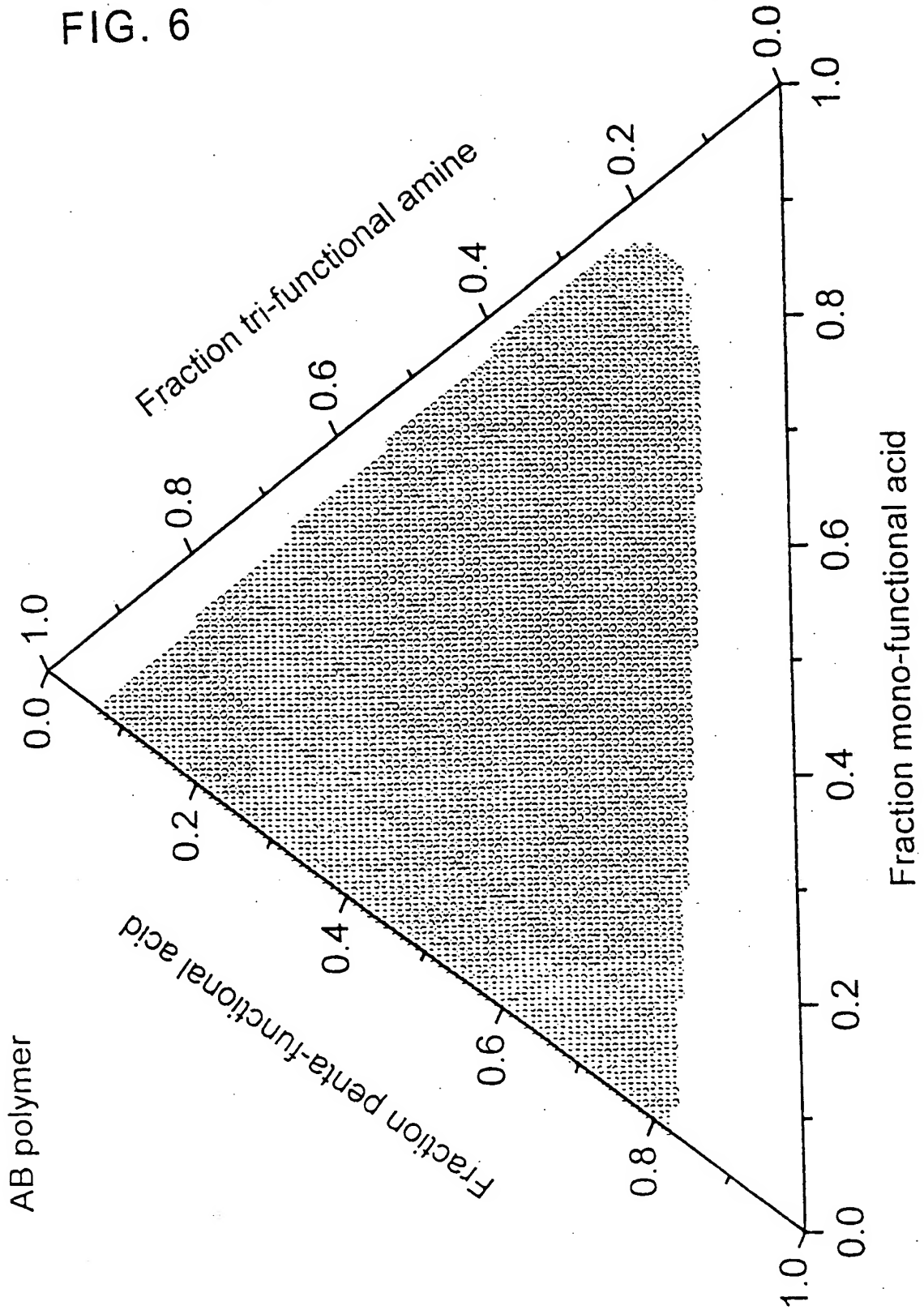

Fraction tri-functional amine
0.0
0.2
0.4
0.6
0.8
1.0
Fraction mono-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
Fraction penta-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
AB polymer

FIG. 7

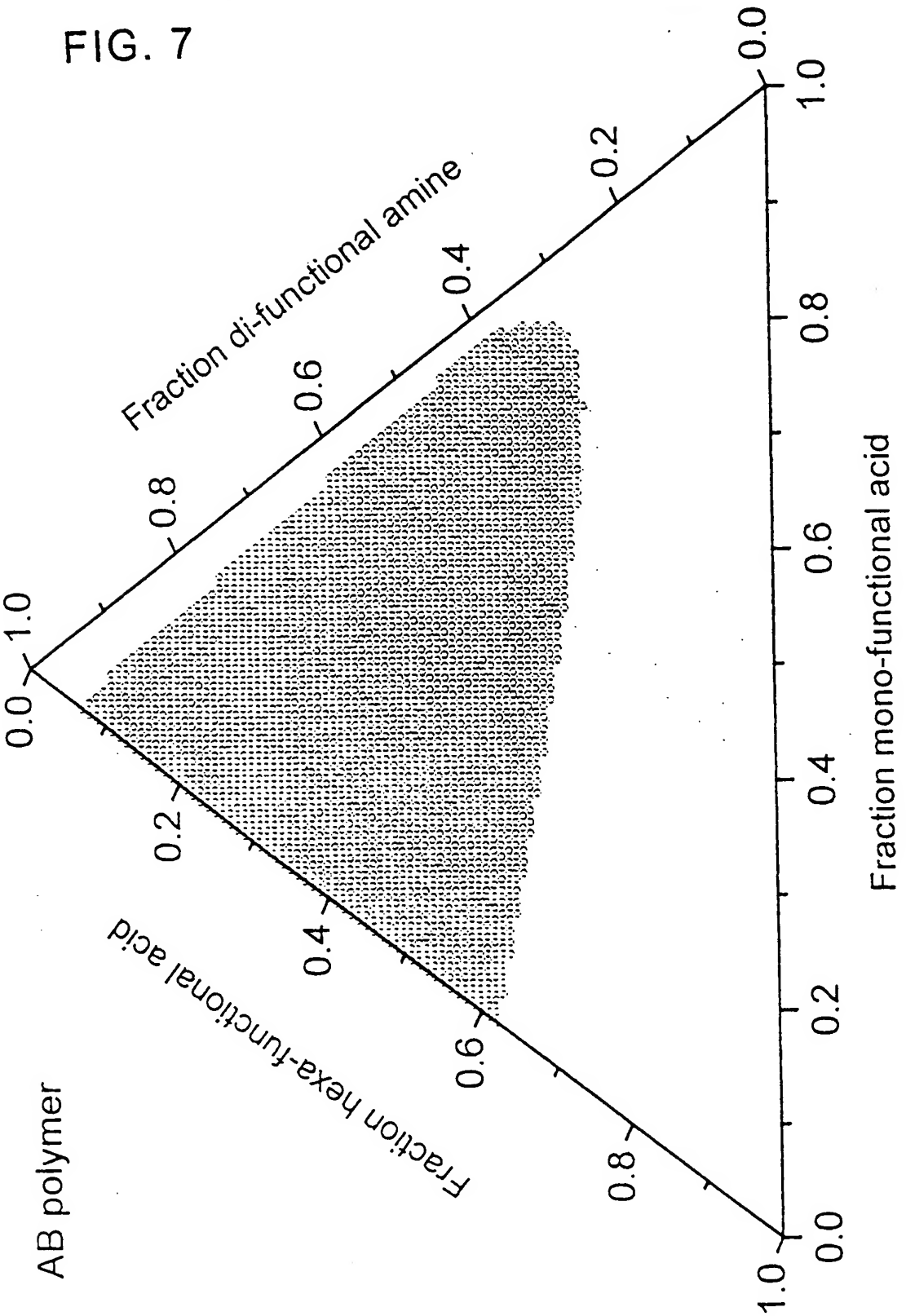
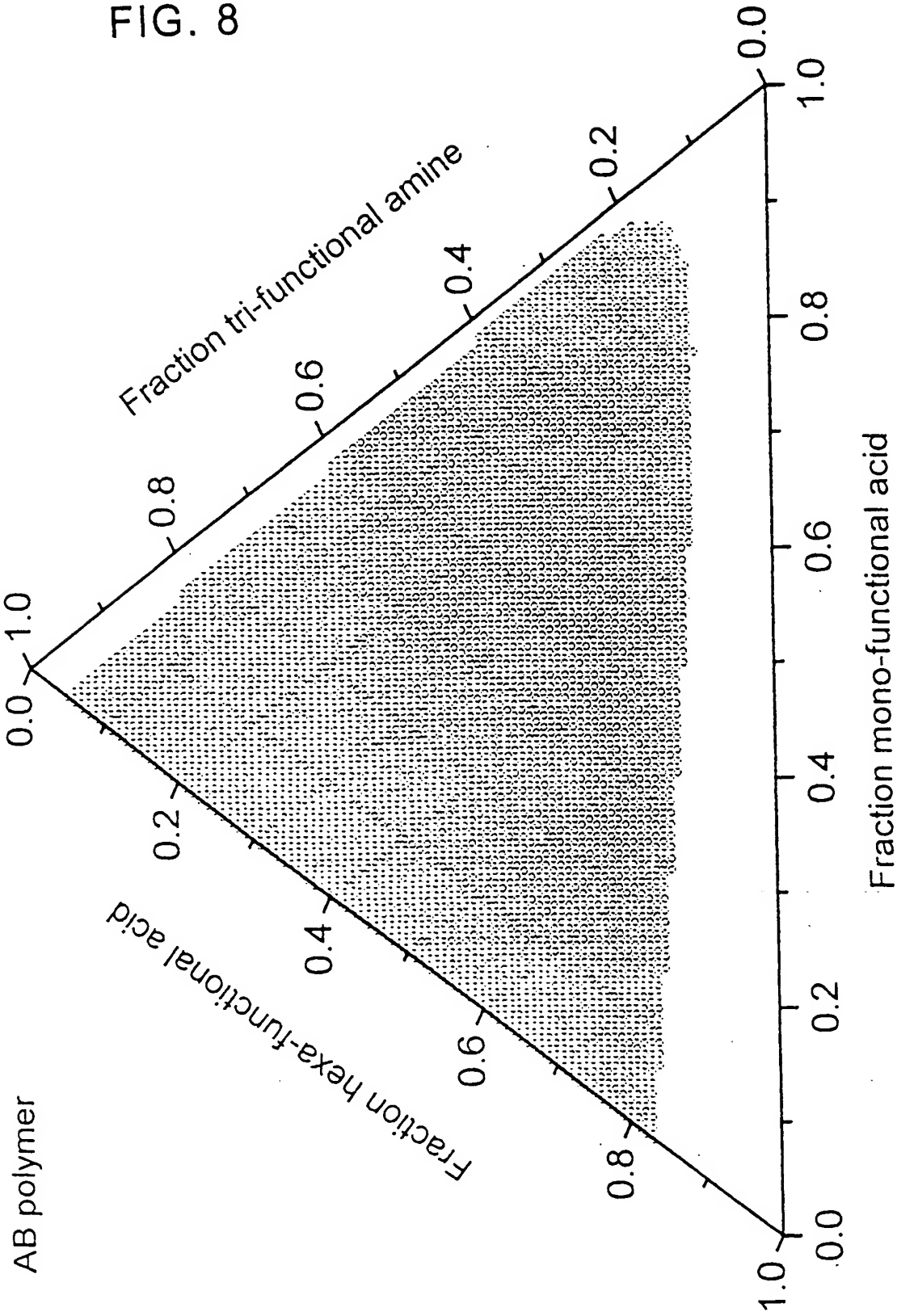
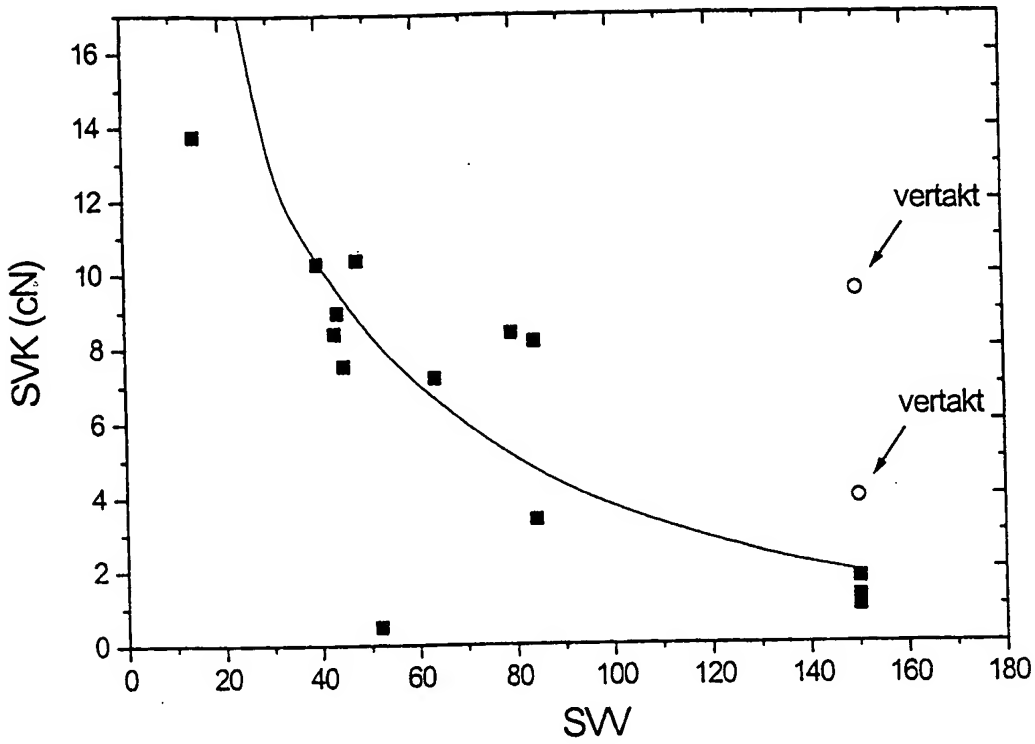

Fraction di-functional amine
0.0
0.2
0.4
0.6
0.8
1.0
Fraction mono-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
Fraction hexa-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
AB polymer

FIG. 8


Fraction tri-functional amine
0.0
0.2
0.4
0.6
0.8
1.0
Fraction mono-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
Fraction hexa-functional acid
0.0
0.2
0.4
0.6
0.8
1.0
AB polymer



■ : linear polyamide ; o : branched polyamide according to the invention.

SVK : melt drawing force

SVV : melt drawing degree

INTERNATIONAL SEARCH REPORT

Internat. Application No
PCT/NL 99/00764

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C08G69/48 C08G69/08 C08G69/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C08G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 345 648 A (INVENTA AG) 13 December 1989 (1989-12-13) cited in the application	
A	WO 97 24388 A (NYLTECH ITALIA ;SNIARICERCHE (IT); CUCINELLA ANTONINO (IT); SILVES) 10 July 1997 (1997-07-10)	
A	EP 0 149 986 A (MONSANTO CO) 31 July 1985 (1985-07-31)	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
3 April 2000	12/04/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax (+31–70) 340–3016	Leroy, A

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Form PCT/ISA/210 (second sheet) (July 1992)

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